LOUDNESS AND ANNOYANCE RESPONSE TO SIMULATED OUTDOOR AND INDOOR SONIC BOOMS

by

Jack D. Leatherwood and Brenda M. Sullivan

SUMMARY

The sonic boom simulator of the Langley Research Center was used to quantify subjective loudness and annoyance response to simulated indoor and outdoor sonic boom signatures. The indoor signatures were derived from the outdoor signatures by application of house filters that approximated the noise reduction characteristics of a residential structure. Two indoor listening situations were simulated: one with the windows open and the other with the windows closed. Results were used to assess loudness and annoyance as sonic boom criterion measures and to evaluate several metrics as estimators of loudness and annoyance. The findings indicated that loudness and annoyance were equivalent criterion measures for outdoor booms but not for indoor booms. Annoyance scores for indoor booms were significantly higher than indoor loudness scores. Thus annoyance was recommended as the criterion measure of choice for general use in assessing sonic boom subjective effects. Perceived Level was determined to be the best estimator of annoyance for both indoor and outdoor booms, and of loudness for outdoor booms. It was recommended as the metric of choice for predicting sonic boom subjective effects.

INTRODUCTION

NASA Langley Research Center is supporting NASA High-Speed Research Program efforts to develop an updated technology base for future high-speed civil transport aircraft (HSCT). Two important parts of the effort include (a) quantification of potential benefits, in terms of reduced subjective loudness and annoyance, of sonic boom shaping and (b) determination of sonic boom exposures that may be acceptable to the general public. These are important because the economic viability of an HSCT would be significantly enhanced if it were permitted to fly over land at supersonic speeds. Experimental studies, using a new sonic boom simulator, are underway at Langley Research Center to quantify subjective loudness and/or annoyance effects for a wide range of simulated sonic boom signatures. Overall objectives include identification of preferred signature shapes for minimum sonic boom loudness and/or annoyance, development and refinement of a sonic boom loudness and/or annoyance prediction model, and development of sonic boom acceptance criteria.

Benefits of boom shaping for simulated outdoor symmetrical N-wave signatures were explored in references 1 and 2. These demonstrated that substantial reductions in subjective loudness of N-waves, for constant peak overpressure, resulted from increases in rise time of the front and rear shocks. Other studies (references 3 and 4) showed that sonic boom loudness could be reduced by more detailed shaping of the signatures such as replacing the N-wave signatures with signatures that achieved peak overpressure in two distinct pressure rises instead of one. Booms shaped in this manner are called front shock minimized (FSM) signatures. Results indicated that FSM booms provided significant loudness reductions relative to N-waves having the same peak overpressure.

Two of the studies described above (refs. 2,4) also investigated the performance of several metrics as loudness estimators for simulated outdoor N-wave and FSM booms. The metrics were Stevens Mark VII Perceivel Level, Zwicker Loudness Level, A-weighted sound exposure level, C-weighted sound exposure level, and unweighted sound exposure level. Results showed Perceived Level, A-weighted sound exposure level, and Zwicker Loudness Level were the best loudness estimators and that any one of the three could be used as predictors of loudness for outdoor signatures.

Two points should be considered when evaluating the findings of references 1 to 4. First, the subjective evaluation criterion was loudness and, second, the booms represented signatures heard outdoors. Whether loudness is the appropriate criterion measure for booms heard indoors is uncertain. Indoor sonic boom pressure time histories and spectral content will differ considerably from outdoor signatures for several reasons. These include: (a) attenuation of high frequency spectral components with a consequent increase in relative emphasis of the low frequency components of indoor boom spectra, (b) loss of distinct rise time characteristics , and (c) room acoustics. All of these factors may alter loudness and/or annoyance perceptions of indoor booms. For example, the low frequency components could introduce annoyance not present in outdoor booms. Studies of annoyance response to sonic booms and subsonic aircraft noise (refs. 5-9) inferred that people may judge the loudness or annoyance of these noises, when heard indoors, by different criteria as compared to the same noises heard outdoors.

The specific objectives of this study included: (a) investigation of loudness and annoyance response to simulated N-wave and FSM booms as heard outdoors and indoors; (b) determination of the appropriate criterion measures (that is, loudness or annoyance) for use in soliciting subjective reactions to outdoor and indoor booms, and (c) evaluation of several loudness metrics as estimators of subjective response to indoor and outdoor booms. Note that subjective perceptions of indoor booms may be influenced by a number of other factors. These include building vibrations and the rattle sounds caused by these vibrations. Investigation of these factors was beyond the scope of the present study and were not considered.

EXPERIMENTAL METHOD

Sonic Boom Simulator

The experimental apparatus used in this study was the Langley Research Center’s sonic boom simulator described in reference 2. The simulator, shown in figure 1, is a person-rated, airtight, loudspeaker-driven booth capable of accurately reproducing user-specified sonic boom signatures at peak sound pressure levels up to 138 dB. Input waveforms were computer-generated and pre-distorted to compensate for irregularities in the frequency and phase response characteristics of the booth. Pre-distortion was accomplished by means of a digital broadband equalization filter (ref. 10). Construction details, performance capabilities, and operating procedures for the sonic boom simulator are given in reference 2.

Test Subjects

Seventy-two test subjects (22 males, 50 females) were used in the experiment. The subjects were obtained from a subject pool of local residents and were paid for their participation in the study. Ages of the test subjects ranged from 19 to 59 years with a median age of 32 years. All subjects were audiometrically screened prior to the test in order to insure normal hearing.

EXPERIMENTAL DESIGN

Test Stimuli

General.- The test stimuli consisted of 135 simulated N-wave and FSM signatures representative of those heard outdoors and indoors. Forty-five of the stimuli were simulated outdoor booms. The remaining 90 stimuli were simulated indoor booms obtained by modifying the outdoor booms to approximate two indoor listening conditions. The modifications involved application of two "house filters" to the outdoor signatures. One house filter approximated the frequency dependent noise reduction characteristics associated with transmission of sound into a typical residential structure with the windows closed. The other filter represented transmission with the windows open. The amplitude-frequency characteristics of the two house filters are shown in figure 2. These are similar to two noise reduction models described in references 9 and 11 for frequencies greater than 10 Hz. For frequencies below 10 Hz the filters of the present study were assumed to have zero noise reduction. This assumption was based in part upon consideration of acoustic leakage paths (which exist in typical structures) that result in zero noise reduction as frequency approaches zero, and in part on the difficulty involved in specifying a "typical" noise reduction characteristic for frequencies less than 10 Hz. At these frequencies noise reduction depends strongly upon specific wall and room properties. Since these frequencies would be expected to have minimal effect on loudness the assumption of zero low frequency noise reduction was considered reasonable.

Outdoor Booms.- The outdoor signatures consisted of three boom types which are displayed in figures 3(a)-3(c). These were: N-waves [fig 3(a)], FSM signatures with the ratio of front shock overpressure to peak overpressure equal to 0.50 [fig 3(b)], and FSM signatures with the ratio of front shock overpressure to peak overpressure equal to 0.75 [fig 3(c)]. All signatures had durations of 300 milliseconds. Both FSM signatures had secondary rise times of 60 milliseconds. Each boom type was assigned rise times of 2, 4, and 8 milliseconds, resulting in nine distinct outdoor shapes. All boom signatures were symmetrical. For simplicity the FSM booms having a front shock overpressure to peak overpressure ratio of 0.50 are referred to as MIN50 booms and those having a ratio of 0.75 as MIN75 booms. Each of the nine shapes (three boom types times three rise times) were presented at five peak overpressure levels to give a total of 45 outdoor signatures.

Indoor Booms.- The indoor signatures were obtained by applying each house filter shown in figure 2 to the outdoor booms. This resulted in 45 signatures representing an indoor-windows closed condition and 45 signatures representing an indoor-windows open condition. Examples of each boom shape (that is, boom type/rise time combination), measured within the simulator are shown in figures 4 through 6. Note in particular the rounded appearance and loss of rise time definition for the indoor signatures.

The 145 boom signatures were randomly assigned and randomly sequenced in three sessions of 45 signatures each. To reduce order effects the booms within each session were presented in reverse sequence to one-half of the subjects. To further minimize order effects the presentation sequences of the sessions were counterbalanced by application of balanced latin squares. One group of 36 test subjects evaluated the stimuli using loudness as the criterion measure. Another group of 36 test subjects used annoyance as the criterion measure.

Scaling Method

The scaling method used was magnitude estimation. The validity of this method for measurment of sonic boom subjective loudness was demonstrated in reference 12. In particular, the ratio properties of magnitude estimation scaling make it very useful for describing and interpreting loudness and annoyance results obtained from sonic boom subjective response studies.

The magnitude estimation procedure used is summarized as follows: A sonic boom stimulus, designated as the standard, was presented to a subject. This standard was assigned a loudness (or annoyance) value of 100 by the experimenter. The standard was then followed by three comparison (test) stimuli. The task of a subject was to rate the loudness (or annoyance) of each comparison stimulus as compared to the loudness (or annoyance) of the standard. For example, if a subject felt that a comparison stimulus was twice as loud (or annoying) as the standard, then he/she would assign it a value of 200. If the comparison stimulus was felt to be only one-fourth as loud (or annoying) as the standard, then the subject would assign it a value of 25. After three comparison stimuli were evaluated, the standard was repeated and another three comparison stimuli judged. This standard-comparison sequence was continued until the 45 test stimuli assigned to a session were evaluated. The subjects were free to assign any number of their choosing (except negative numbers) to reflect their loudness (or annoyance) opinions. The standard used in this study was a symmetrical N-wave signature with a rise time of three milliseconds and a peak overpressure of 0.89 psf. The instructions explaining how to use the magnitude estimation procedure are given in Appendix A for the loudness criterion. Annoyance instructions were similar except that loudness was replaced by annoyance. An example of a magnitude estimation scoring sheet is shown in Appendix B.

Test Procedure

Test subjects were delivered to the laboratory in groups of four, with one group in the morning and one group in the afternoon on any given day. Upon arrival at the laboratory each group was briefed on the overall purpose of the experiment, system safety features, and their rights as test subjects. A copy of these briefing remarks is given in Appendix C. The subjects were then given specific instructions related to the test procedure to be followed and to the use of the magnitude estimation procedure (see Appendix A). At this point the subjects were taken individually from the waiting room to the sonic boom simulator. At the simulator the magnitude estimation scoring procedure was reviewed and the subject listened to several boom stimuli, played with the simulator door open, in order to become familiar with the type of sounds he/she would be asked to evaluate. The subject was then given a practice scoring sheet and seated in the simulator with the door closed. A practice session was then conducted in which the subject rated a set of practice stimuli similar to those used in the actual test sessions. Upon completion of the practice session the practice scoring sheet was collected and any questions were answered. The actual test session was then conducted. After all subjects completed the first session they were then cycled through sessions 2 and 3. No further practice sessions were given.

Data Analysis

The boom pressure time histories measured (within the simulator) were computer-processed to calculate sound exposure level in terms of three frequency weightings and to calculate two loudness metrics. The sound exposure level metrics were: unweighted sound exposure level (L_{ue}), C-weighted sound exposure level (L_{CE}), and A-weighted sound exposure level (L_{AE}). The loudness metrics were Stevens Mark VII Perceived Level (PL) and Zwicker Loudness Level (LLZ). The calculation procedure for PL was based on the method described in reference 11.

The central tendency parameter used to characterize the subjective rating scores was the geometric means of the magnitude estimates for each stimulus. It is customary (see reference 13, for example) to use geometric averaging with magnitude estimation since the distribution of the logarithms of the magnitude estimates is approximately normal. Furthermore, subjective loudness (or annoyance) is a power function of the physical intensity of a sound. Such a power function is linear when expressed in terms of the logarithms of the subjective loudness (or annoyance) and sound pressure level, dB.

DISCUSSION OF RESULTS

Loudness and Annoyance Response Considerations

Overall Results.- The logarithm of the geometric means of the loudness and annoyance scores for the complete stimuli set are shown in figures 7(a)-7(e) for each of the five metrics. Also shown are the best-fit linear regression lines calculated for each subjective response criterion. These data indicate that annoyance and loudness scores generally differed for all metrics. Dummy variable analysis indicated that each pair of regression lines differed in slope and/or offset. This implies that loudness and annoyance were not equivalent criterion measures. To more completely assess the implication and extent of these results, the data were considered at an additional level of detail. Specifically, the differences between loudness and annoyance responses were examined for each of the three simulated listening conditions: outdoors, indoors-windows closed, and indoors-windows open.

Loudness vs Annoyance Comparison.- Comparisons of the logarithms of the geometric means of the loudness and annoyance magnitude estimates are displayed in figures 8(a)-8(c) as a function of Perceived Level for the outdoors, indoors-windows closed, and indoors-windows open signatures. Linear regression lines calculated using the data for each criterion measure are also shown. Perceived Level was used based upon its demonstrated ability to predict the loudness of shaped booms (see refs. 2 and 4).

Figure 8(a) shows that loudness and annoyance responses were very similar for the outdoor signatures. Thus loudness ratings of the outdoor booms also represented annoyance outdoors. This was not true for the two indoor conditions. Figures 8(b) and 8(c) indicate that loudness scores for the indoor booms were lower than annoyance scores for these booms, especially for the windows closed condition. Dummy variable analysis showed these differences to be statistically significant (probability < 0.001) and that the slopes of the two lines in each figure were equal. In terms of PL, the difference between each pair of lines in figures 8(b) and 8(c) (based on the dummy variable regression analysis) was equivalent to 4.2 dB for the windows closed condition and 1.6 dB for the windows open condition.

The regression lines of figure 8 were grouped in terms of loudness and annoyance and are presented in figures 9(a) and 9(b), respectively, for the three listening conditions. Figure 9(a) shows that, in terms of loudness, the indoor booms were rated as being less loud than the outdoor booms for equivalent PL. The largest differences were observed for the windows closed condition. In terms of annoyance, however, the indoor and outdoor booms were rated approximately equally annoying as indicated in figure 9(b).

Dummy variable analysis confirmed that the loudness differences [figure 9(a)] were significant and that the annoyance differences [figure 9(b)] were not significant. Thus, PL was an effective estimator of annoyance for all simulated listening conditions, but was not an effective estimator of loudness. None of the remaining metrics performed better than PL. For example, the regression lines for each listening condition obtained using C-weighted Sound Exposure Level, L_{CE}, as the independent variable are displayed in figures 9(c) and 9(d). These results show that L_{CE} did not account for subjective response differences due to listening condition for either subjective criterion measure.

The reasons for the differences between outdoor and indoor loudness responses for equal PL are unclear. These booms differed primarily in spectral content. The house filters progressively attenuated the high frequency components (greater than 10 Hz) of the outdoor boom spectra, resulting in indoor signatures having higher proportions of very low-frequency (below 10 Hz) energy than outdoor signatures and increased high frequency roll-off rates. Consequently, when matched on the basis of PL, the relative level of the low frequency energy of the indoor signatures substantially exceeded that of the outdoor booms. This was particularly true of the windows closed signatures. These differences in spectral "balance" between outdoor and indoor signatures may have been a contributing factor to the observed results although the exact mechanisms by which this could occur are uncertain. One possibility is that the relatively intense low frequency energy in the indoor boom spectra, although not audible, did result in an upward spread of loudness masking (see reference 14 for a discussion of masking). Another possibility is that the low frequency energy introduced an annoyance factor which interfered with, or detracted from, the loudness perceptions. The presence of such an annoyance factor was demonstrated by the significantly higher annoyance scores (as compared to loudness scores, see figure 8) given to the indoor booms.

The above results imply that sonic boom criterion levels based upon indoor loudness judgments may not accurately reflect the actual subjective acceptability of booms heard indoors. Furthermore, additional factors such as contextual effects, fear of structural damage, interference with daily activities, rattle, and window/wall/floor vibration may further increase annoyance, and reduce acceptability of indoor sonic booms. Thus future sonic boom subjective tests (and surveys) conducted within actual residences should require subjects to make annoyance (or acceptability) judgments in lieu of loudness judgments.

Metric Considerations

Previous studies (refs 2,4) determined that PL, L_{AE}, and LLZ were the best estimators of the loudness of simulated outdoor booms. Those conclusions were based upon consideration of the degree of relationship between each metric and subjective loudness and upon the prediction accuracy of each metric. The degree of relationship was defined by the linear correlation coefficients and prediction accuracy by the standard errors of estimate of the regression lines describing the relationship between subjective loudness or annoyance response and metric level for each metric. These parameters were calculated for each metric and criterion measure of the present study. The correlation coefficients are presented in Table 1 and the standard errors of estimate in Table 2. The two parameters were calculated for (a) the total stimuli set (135 booms), (b) the outdoor signatures (45 booms), (c) the indoor-windows open signatures (45 booms), and (d) the indoor-windows closed signatures (45 booms).

Tables 1 and 2 indicate that the correlations obtained using the **loudness criterion** were generally consistent with the earlier findings with the exception that LLZ did not perform as well for the indoor conditions. Correlations obtained using the **annoyance criterion**, however, were not fully consistent with those of the earlier studies nor with the loudness results of the present study. For example, the highest annoyance correlation coefficients were obtained for PL and LLZ. The L_{AE} correlations with annoyance were significantly lower than those obtained for loudness. Note also that L_{CE} and L_{UE} correlation coefficients for the annoyance criterion were significantly higher than those for the loudness criterion. The reduced performance of L_{AE} and improved performance of L_{CE} and L_{CE} for annoyance relative to loudness implies that the low frequency content of the booms was more important for annoyance than loudness. This is consistent with the results described earlier which showed that the annoyance scores were higher than loudness scores for the indoor booms. Generally the standard errors of estimate (see Table 2) for each metric, except L_{AE}, were smaller for the annoyance criterion. This means that annoyance was estimated with less error than loudness for all metrics except L_{AE}.

The above results, when considered in combination with those of previous studies, provide a basis for recommending a preferred criterion measure and a preferred metric for general use in assessing subjective effects of sonic booms. The preferred criterion measure is annoyance and the preferred metric is PL. Selection of annoyance as the criterion measure is based on (a) the presence of an additional annoyance component for the indoor booms (as evidenced by the higher annoyance scores) and (b) the improved prediction accuracies when annoyance was the criterion. Selection of PL as the best metric was based on the demonstrated ability of PL to account for loudness effects of outdoor booms and annoyance effects of both indoor and outdoor booms.

Conclusions

The sonic boom simulator of the Langley Research Center was used to quantify subjective loudness and annoyance response to simulated indoor and outdoor sonic boom signatures. The indoor signatures were derived from the outdoor signatures by application of house filters that approximated the noise reduction characteristics of a residential structure. Two indoor listening conditions were simulated: one with windows open and the other with windows closed. Results were used to assess loudness and annoyance as sonic boom criterion measures, and evaluate several metrics as predictors of loudness and/or annoyance. Specific findings, comments, and conclusions derived from this study are summarized as follows:

1. Loudness and annoyance were equivalent criterion measures for outdoor booms but not for indoor booms. Indoor boom annoyance scores were

significantly higher than indoor boom loudness scores. The average difference between indoor annoyance and indoor loudness scores was equivalent to about 4.2 dB(PL) for the windows closed condition and 1.6 dB(PL) for the windows open condition. These differences do not reflect the effects of additional potential annoyance contributors such as window/wall rattle, activity/task interference, and fear of damage.

2. Perceived Level (PL) was the best estimator of annoyance for both outdoor and indoor booms and the best estimator of loudness for the outdoor booms only. It is recommended as the metric of choice for assessment and prediction of sonic boom subjective effects.
3. Annoyance was found to be the most appropriate criterion measure to use when studying sonic boom subjective effects. Prediction accuracies of all metrics (except A-weighted sound exposure level) were highest for the annoyance criterion. Also the ability of all metrics, except A-weighted sound exposure level, to account for indoor and outdoor boom differences was much improved for the annoyance criterion. It is recommended that future sonic boom subjective studies use annoyance (or perhaps acceptability) as the measurement criterion.
4. The specification of acceptable indoor sonic boom criteria levels should be based on subjective annoyance (or acceptability) data. If based on subjective loudness data a correction may be required to account for annoyance effects.

Appendix A.- Magnitude Estimation Instructions for Loudness

SPECIFIC INSTRUCTIONS

This test will consist of three test sessions. Prior to the first test session each of you will be taken individually to the simulator where you will listen to sounds that are similar to those you will be asked to rate. We will then place you in the simulator and a practice scoring session will be conducted. Upon completion of the practice session we will collect the practice rating sheets and answer any questions you may have concerning the test. At this point the first actual test session will be conducted. You will then return to the waiting room while the other members of your group complete a similar test. You will return to the simulator two more times to complete the remaining two test sessions.

During a test session we will play a series of sonic booms over the loudspeakers in the door of the simulator. The first sonic boom that you hear, and every fourth boom thereafter, will be a **REFERENCE** boom that you will use to judge how loud the other booms are. In order to help you keep track of which boom is the **REFERENCE** boom, it will always be preceded by a short beep. The **REFERENCE** boom will remain the same throughout the test. Your task will be to tell us how loud each of the other booms are as compared to the **REFERENCE** boom. You will be provided rating sheets for use in making your evaluations. The rating sheets will indicate when a **REFERENCE** boom will be played and the sequence of **REFERENCE** and other booms will be organized as follows:

```
 <------------------------- beep
R =100 <------------------ reference
1. ______
2. ______
3. ______
<-------------------------- beep
R=100<-------------------- reference
4. ______
5. ______
6. ______
```

The scoring procedure will be as follows: The short beep will indicate to you that the boom which follows is the **REFERENCE** boom. Please listen to it carefully because you will compare the other booms to it. For this purpose the **REFERENCE** boom will be assigned a loudness level of 100. Thus you do not score the **REFERENCE** boom because it will always have an loudness level of 100. You will then hear a sequence of three comparison booms. After listening to each comparison boom you should decide how loud it is relative to the **REFERENCE** boom and assign it a number accordingly. This number will be entered on the appropriate line of the scoring sheet. For example, if you feel the comparison boom is three times louder than the **REFERENCE** boom then you would give it a loudness score of 300. If you think the comparison boom is only one-fourth as annoying as the **REFERENCE** boom you would give it a loudness score of 25. You may choose any number you wish as long as it faithfully represents your impression of the relative loudnesses of the comparison and **REFERENCE** booms. After evaluating three comparison booms in this manner you will hear the beep again, followed by the **REFERENCE** boom and three more comparison booms. This will be repeated within a test session until a total of 45 comparison booms have been scored. Remember! There are no right or wrong answers. We are interested only in how loud the booms sound to you.

Appendix B.- Sample Rating Sheet

Appendix C.- General Instructions

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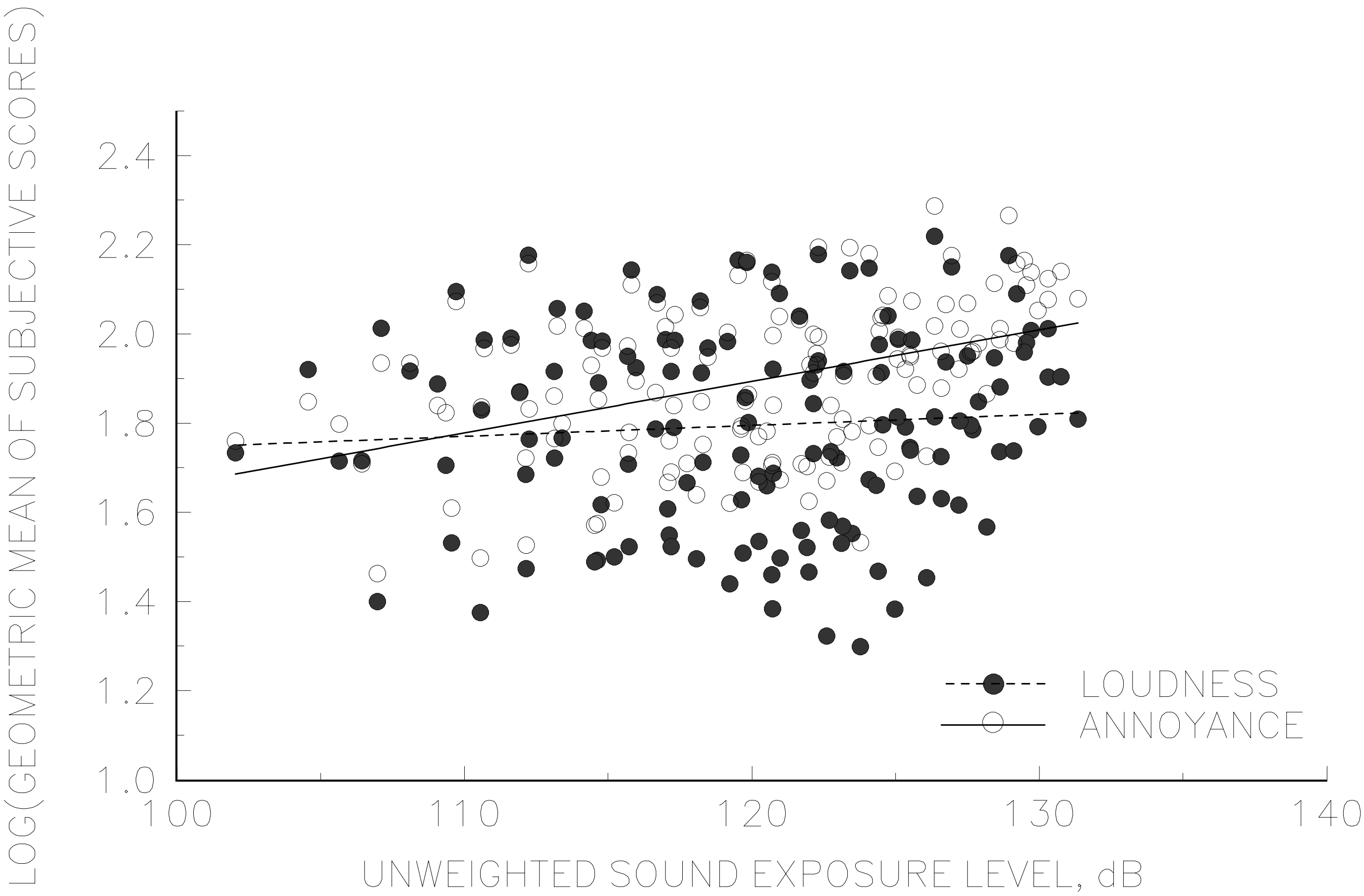
Table 1.- Correlation Coefficients for Each Criterion Measure, Listening Condition, and Metric

		Correlation Coefficient	
Condition	Metric	Loudness	Annoyance
Overall	PL	0.9127	0.9507
	LLZ	0.8045	0.9405
	A	0.9568	0.8679
	C	0.4737	0.7649
	LIN	0.0721	0.4265
Outdoor	PL	0.9570	0.9732
	LLZ	0.9153	0.9688
	A	0.9441	0.8979
	C	0.8116	0.9044
	LIN	0.6499	0.7705
Windows Open	PL	0.9459	0.9231
	LLZ	0.8985	0.9379
	A	0.9278	0.8220
	C	0.8021	0.9144
	LIN	0.6784	0.8423
Windows Closed	PL	0.9546	0.9498
	LLZ	0.8904	0.9327
	A	0.9670	0.9180
	C	0.8224	0.9059
	LIN	0.6547	0.7859

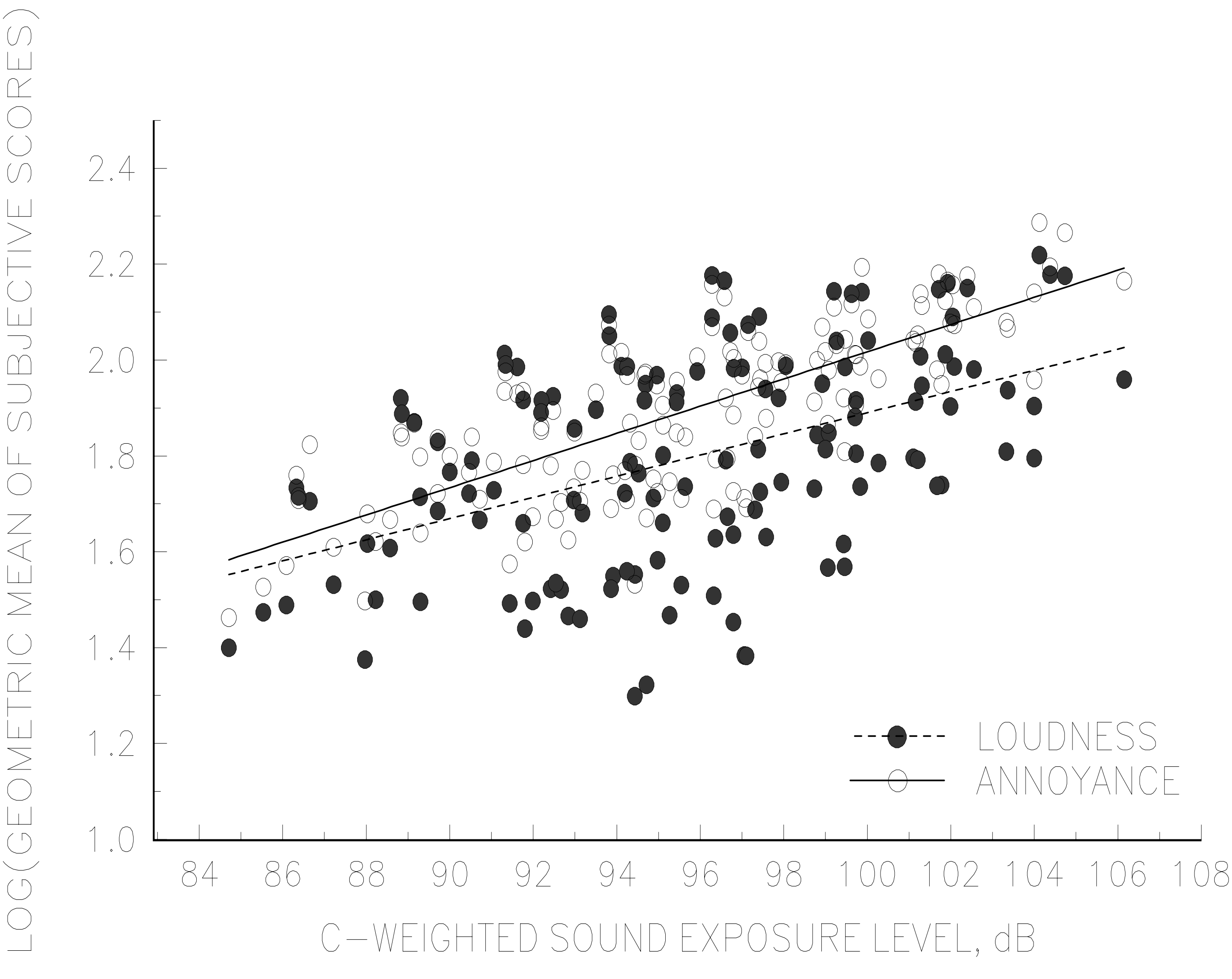
Table 2. Standard Errors of Estimate for Each Criterion Measure, Listening Condition, and Metric

		Standard Error of Estimate	
Condition	Metric	Loudness	Annoyance
Overall	PL	0.0909	0.0549
	LLZ	0.1321	0.0601
	A	0.0647	0.0879
	C	0.1959	0.1140
	LIN	0.2219	0.1600
Outdoor	PL	0.0428	0.0327
	LLZ	0.0595	0.0353
	A	0.0487	0.0627
	C	0.0863	0.0607
	LIN	0.1123	0.0908
Windows Open	PL	0.0595	0.0656
	LLZ	0.0804	0.0591
	A	0.0684	0.0971
	C	0.1094	0.0690
	LIN	0.1346	0.0919
Windows Closed	PL	0.0582	0.0554
	LLZ	0.0889	0.0639
	A	0.0497	0.0702
	C	0.1112	0.0750
	LIN	0.1477	0.1095



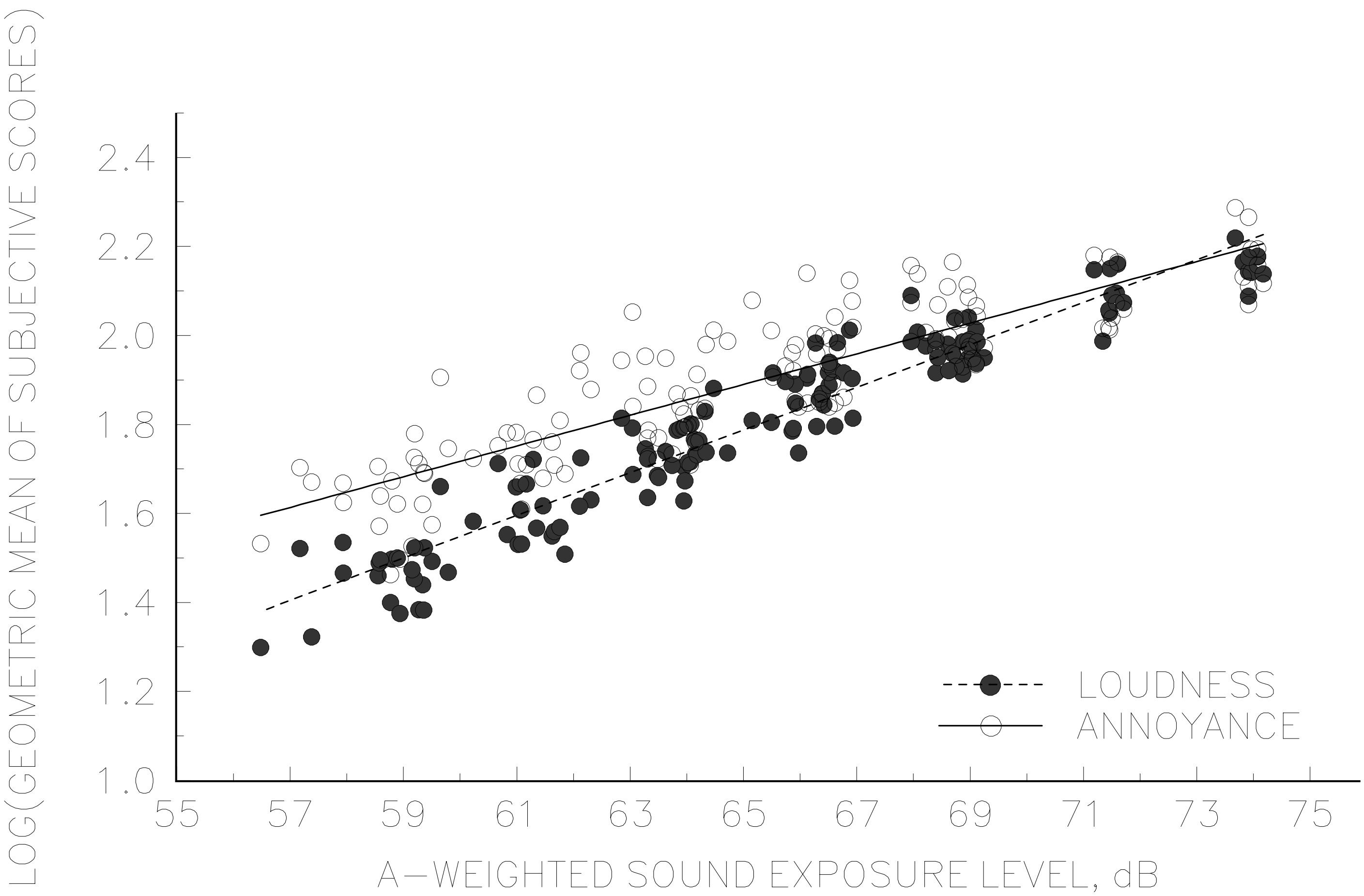
(a) Unweighted sound exposure level

Figure 7.- Loudness and annoyance response (in terms of the logarithms of the geometric means of the subjective scores) for each metric.



(b)C—weighted sound exposure level

Figure 7.- Continued.



(c) A—weighted sound exposure level

Figure 7.- Continued.

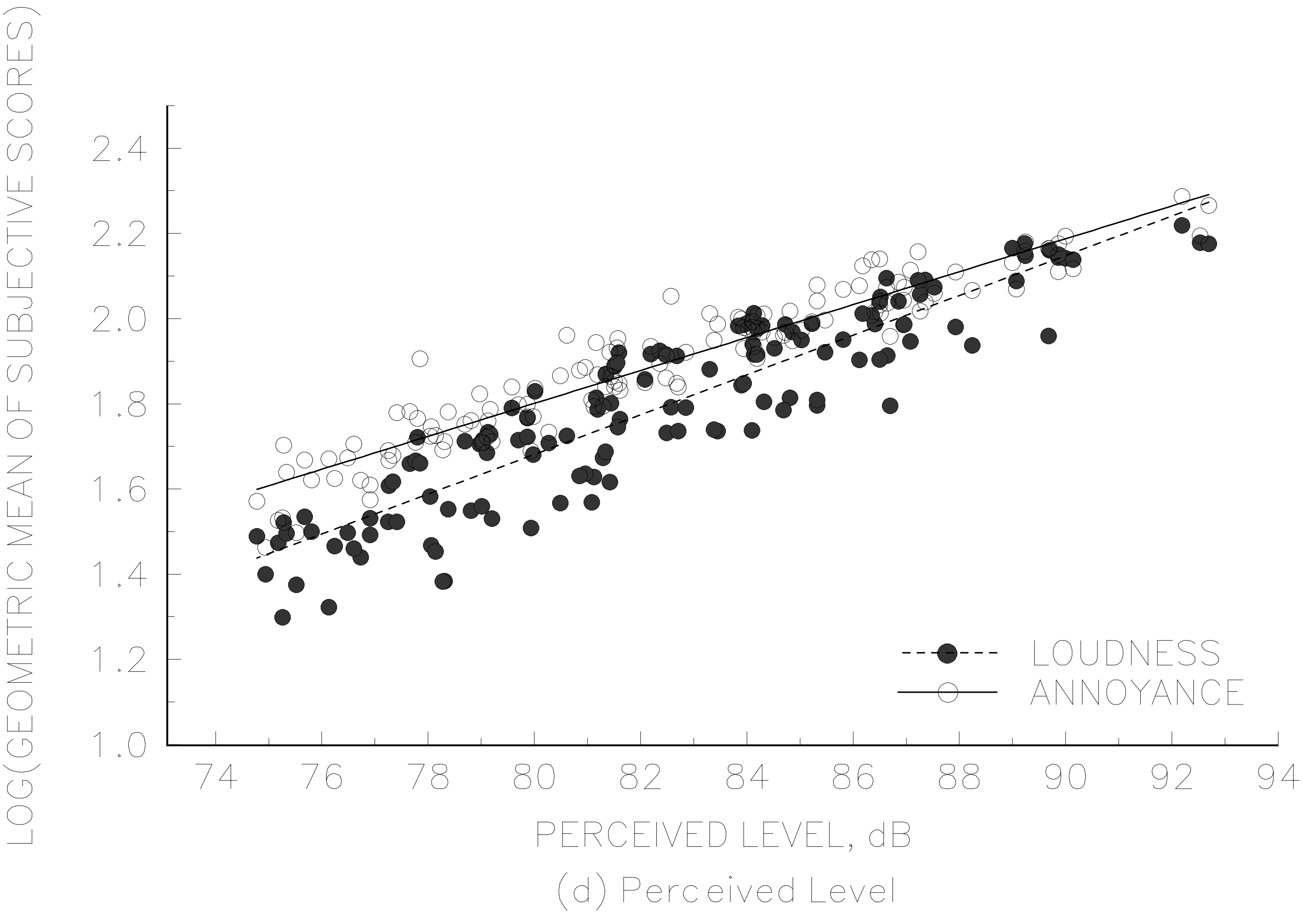
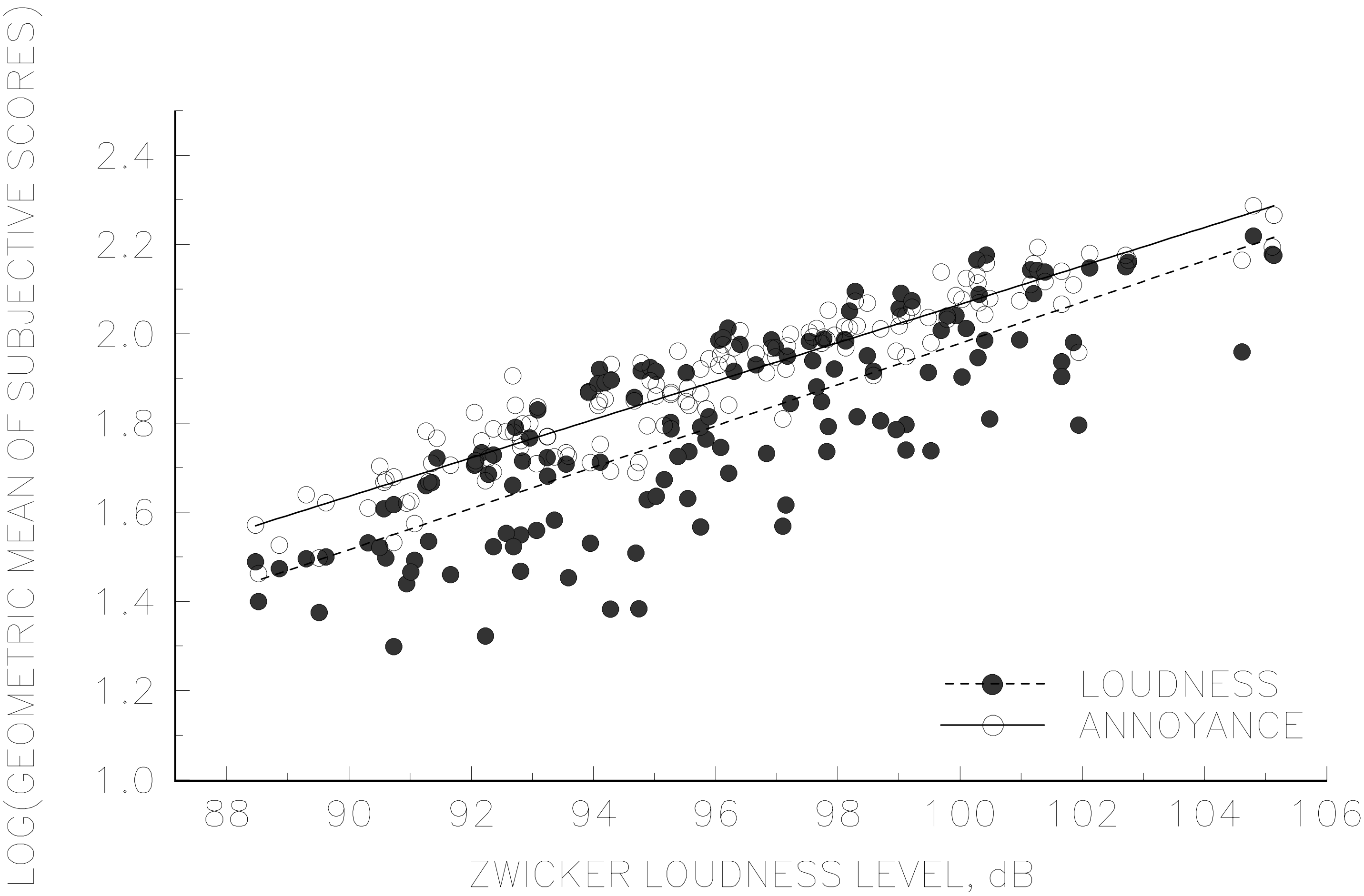


Figure 7.- Continued.



(e) Zwicker Loudness Level

Figure 7.- Concluded.

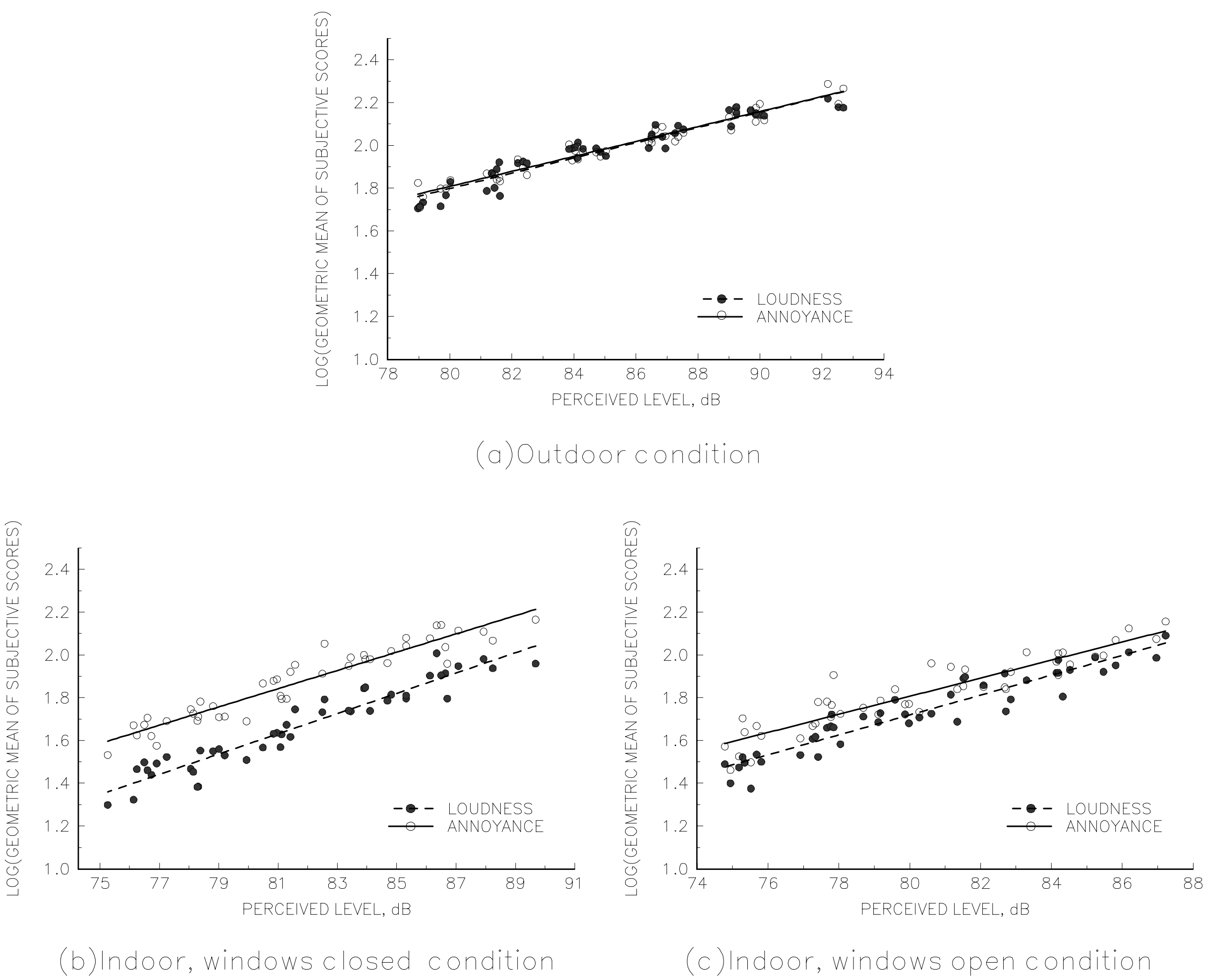


Figure 8.- Loudness and annoyance response comparisons for each simulated listening condition in terms of Perceived Level.

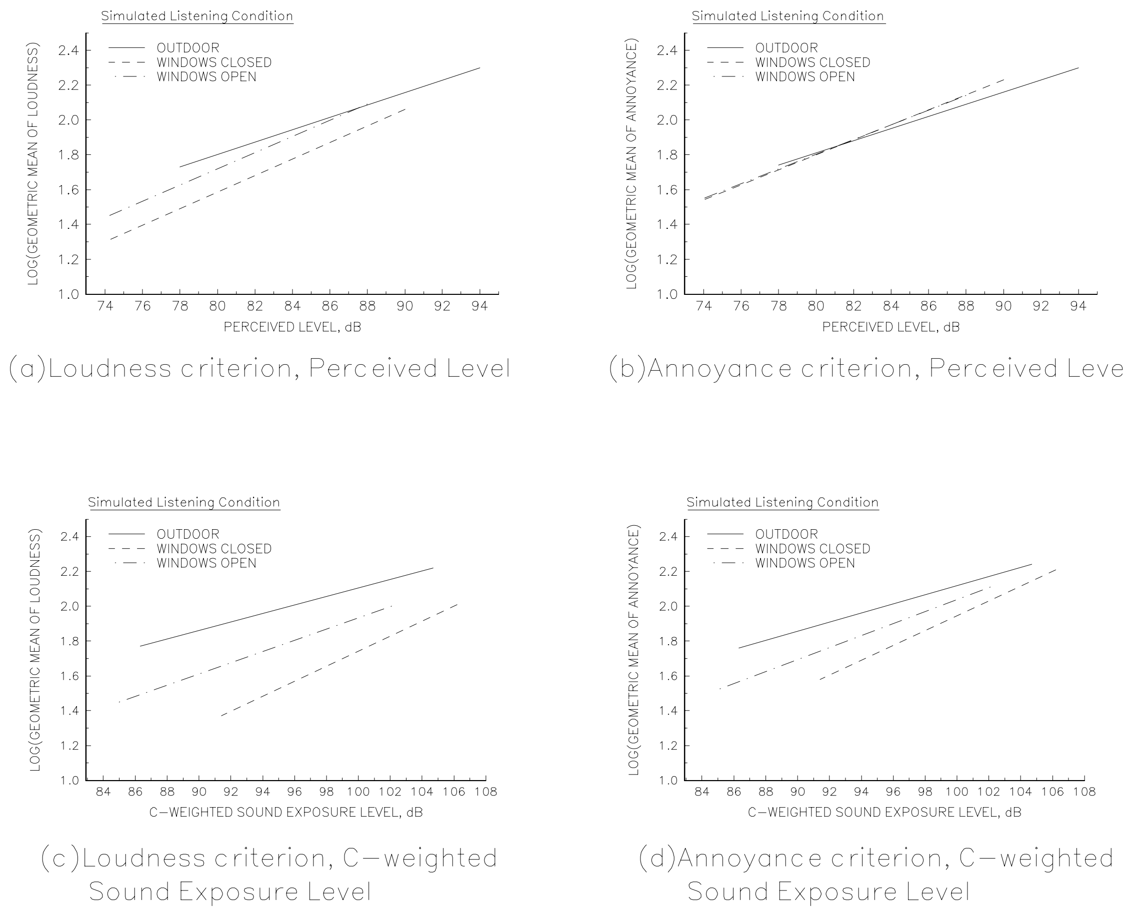


Figure 9.- Loudness and annoyance responses for each simulated listening condition in terms of Perceived Level and C-weighted sound exposure level.